Aerodynamics of speech, and the puzzle of voiced fricatives

Christine H. Shadle, Haskins Laboratories

Aerodynamic principles govern the movement of air in the vocal tract and thus underly all speech sounds; as a result they feature strongly in mechanistic explanations of phonetic universals. Sibilants, especially /s/, are common in the world's languages, but voiced sibilants or indeed voiced fricatives are relatively rare (Ohala 1983, 1994). An aerodynamic explanation has been offered by Stevens (1971): fricatives require a pressure drop across the constriction to generate turbulence and therefore turbulence noise; voicing requires a phonation threshold pressure across the vocal folds; having both sources operating at the same time requires that the subglottal pressure be divided across larynx and constriction. This means that, all else being equal, the frication will be weaker than for voiceless counterparts, and the production task altogether is more complex. Thus, devoicing of voiced fricatives is common, and they tend to be less frequent than their voiceless counterparts within a language. As Ohala (1997) stated, "Fricatives favor voicelessness (more than comparable stops)."

But all else is not equal for voiced and voiceless counterparts. There are articulatory differences: the tongue root is slightly more advanced on average for /z/ than /s/ based on cineradiography of 10 speakers (Subtelny et al., 1972); it is more advanced in all voiced than voiceless English fricatives for three of four MRI subjects (Proctor et al., 2010). The tongue constriction is narrower in voiced, word-initial cases based on EPG data for 10 speakers (McLeod et al., 2006). The aerodynamic reason for such a posture in voiced stops, that the pharyngeal cavity must expand during closure to keep voicing going (Westbury, 1983), does not hold for voiced fricatives where there is no complete closure. There are known aeroacoustic effects of these differences: phonation becomes louder in a model of the vocal folds when a fricative-sized constriction is added downstream (Barney and Jackson, 2008). Ventricular folds increase the flowrate through the vocal folds, indicating that certain kinds of laryngeal postures may change the phonation threshold and/or increase the pressure drop occurring across the fricative constriction. The narrower tongue constriction may be the result of the passive response of tongue tissue to a lower intraoral pressure, or it may reflect a deliberate repositioning of the tongue blade and tip to optimize noise generation in the voiced case. And although measurements of intraoral pressure and volume velocity are consistent with the lower frication energy of /z/ relative to /s/, differences in the trajectory of the constriction area estimated from these aerodynamic parameters between voiced and voiceless fricatives indicate that the rate of onset and offset of turbulence differs as well (Scully, 1971 and Stromberg et al., 1994). Finally, the voicing source modulates frication in voiced fricatives by, apparently, altering the structure of the jet downstream of the constriction, which may result in perceptual cues to place at the onset of frication (Jackson and Shadle, 2000); these may be more obvious when frication is weaker relative to the voicing.

In general, enough interactions are possible between articulatory, aerodynamic and aeroacoustic factors that the simple models showing voiced fricatives are “harder” to produce may not be the best explanation for why voiceless fricatives are favored in the world’s languages. Examining such interactions may also help us to develop better explanations for other phonetic universals.

References

Barney, A. and Jackson, P.J.B.(2008) Analysis of frication noise modulation from a physical model. J. Acoust. Soc. Am. 123:5:2, 3578.

Jackson, P.J.B. and Shadle, C.H. (2000) Frication noise modulated vby voicing, as revealed by pitch-scaled decomposition. J. Acoust. Soc. Am.108:4, 1421-1434.

McLeod, S. , Roberts, A. and Sita, J. (2006) Tongue/palate contact for the production of /s/ and /z/. Clinical Linguistics & Phonetics, 20:1, 51-66.

Ohala , J. (1997) Aerodynamics of phonology. Proc. 4th Seoul International Conf. on Linguistics [SICOL], 11-15 Aug, p. 92-97.

Ohala, J. (1983) The origin of sound patterns in vocal tract constraints, in: P.F. MacNeilage (ed.), The Production of Speech. New York: Springer-Verlag, 189-216.

Ohala, J. (1994) Speech aerodynamics. In R.E. Asher and J.M.Y. Simpson (eds.), The Encyclopedia of Language and Linguistics. Oxford: Pergamon. 4144-4148.

Proctor, M.I., Shadle, C.H. and Iskarous, K. (2010) Pharyngeal articulation in the production of voiced and voiceless fricatives. *J. Acoust. Soc. Am*. 127:3, 1507-1518.

Scully, C. (1971) A comparison of /s/ and /z/ for an English speaker. Language and Speech 14:2, 187-200.

Stevens, K.N. (1971) Airflow and turbulence noise for fricative and stop consonants: static considerations. J. Acoust. Soc. Am. 50:4:2, 1180-1192.

Stromberg, K., Scully, C., Badin, P. and Shadle, C. (1994) Aerodynamic patterns as indicators of articulation and acoustic sources for fricatives produced by different speakers. Proc. Inst. Of Acoust. 16:5, 325-333.

Subtelny, Joanne D., Oya, N. and Subtelny, J.D. (1972) Cineradiographic study of sibilants. *Folia Phoniatrica* 24: 30-50.

Westbury, J. (1983) Enlargement of the supraglottal cavity and its relation to stop consonant voicing, *J. Acoust. Soc. Am*. 73, 1322-1336.